Medicine
TEAM 437

Electrolytes imbalance: Na^+ & Water

Objectives :

1. Recognize the systems that control body sodium and water contents
2. Differentiate between total body sodium content (volume status) and serum sodium concentration (Hypo- and Hypernatremia)
3. Use the different types of IV fluids in clinical practice
4. Calculate the water deficit in Hypernatremia
5. Explain the workup of Hyponatremia

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Resources :

Dr. Tarakji’s handout & notes, Team 436.

Important Notes Golden Notes Extra Book

Basic Information:

Total Body Water:

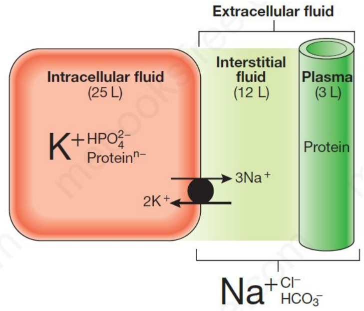


Fig. 14.1 Normal distribution of body water and electrolytes.

Percentage of TBW decreases with age and increasing obesity (TBW decreases because fat contains very little water):

- Men: Total body water (TBW) = 60% of body weight. In a 70 kg 30 y/o man;
  TBW will be 42 L in which 28 L will be intracellular and 14 L extracellular (10.5 L in the interstitium and 3.5 plasma)
- Women: TBW = 50% of body weight. TBW will be 60% for adult male. Around 50 to 55% for female. For pediatric around 80%. Geriatric around 50%

Distribution of water:

- Total Body Water (0.6 x Body Weight)
  - Intracellular (ICF) (2/3 of TBW) (0.4 x Body weight)
  - Extracellular (ECF) (1/3 of TBW) (0.2 x Body weight)
    - Interstitial Fluid (ISF) (3/4 x ECF)
    - Plasma (1/4 x ECF)
      - Venous fluid "Venous capacitance" (85% of plasma)
      - Arterial fluid (15% of plasma)

For body fluid compartments, remember the 60–40–20 rule:

- TBW is 60% of body weight =42 L(50% for women).
- ICF is 40% of body weight =28L
- ECF is 20% of body weight=14L (interstitial fluid 15% =10.5 and plasma 5% =3.5L).

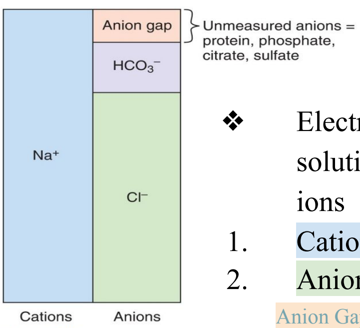


FIGURE 5.25 Serum anion gap.

❖ Electrolytes are substances dissolved in solutions and dissociated into particles called ions

1. Cations: Positively charged ions
2. Anions: Negatively charged ions

Anion Gap reflects unmeasured anions such as Albumin.

Definitions:

- Osmosis: movement of water
- Diffusion: movement of solutes
- Filtration: movement of both solutes and water

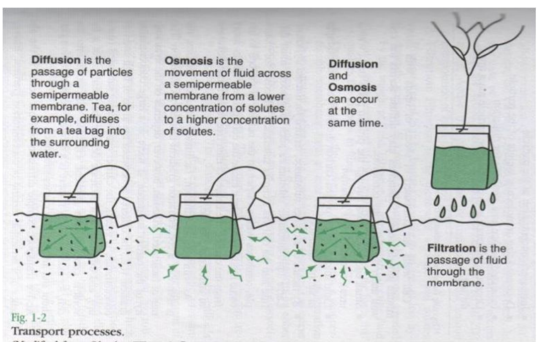


Fig. 1-2 Transport processes.

- If you put a tea bag inside a water cup this is what will happen?
  - First the tea bag will swell; why? Because of osmosis. Water will move from an area of low osmolarity to an area of high osmolarity.
  - Then? Tea solutes come out (diffusion). Remember that solutes diffuse from an area of high conc to an area of low conc.
- What will happen if we lift the teabag up? Both water and tea will come out. This is exactly how the glomeruli filter the plasma.

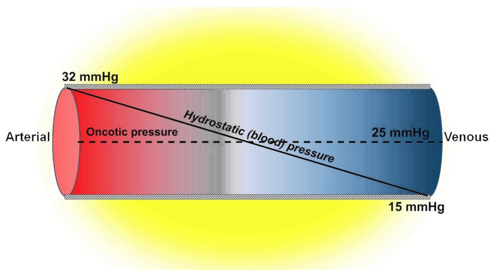
Composition of the fluid compartments:

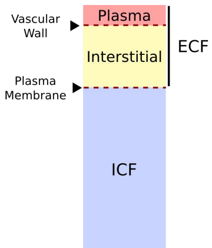
Electrolytes concentration (mmol/L)			
Cations	Plasma ECF	Interstitial fluid	ICF Intercellular fluid
Na⁺	142	144	10
K⁺	4	4	160

- The dominant Cation in the ICF is **potassium (K)**, while in the extracellular fluid (ECF) it is **sodium (Na)**.
  - The major force maintaining the difference in cation concentration between the ICF and ECF is the **sodium–potassium pump.**

- An important difference between the plasma and interstitial ECF is that only plasma contains significant concentrations of **protein**.
  - The difference in protein content between the plasma and the interstitial fluid compartment is maintained by the protein permeability barrier at the capillary wall. (permeability will increase in pathological cases **"Capillary leak syndrome"** in sepsis and septic shock. This clinically manifests as edema).
  - This protein concentration gradient contributes to the balance of forces across the capillary wall that favour fluid retention within the capillaries (the colloid osmotic, or oncotic pressure of the plasma) maintaining circulating plasma volume.

- What is the Starling forces? (see the picture below)
  - **Hydrostatic pressure** (present in the intravascular and in the interstitial compartment) + **Oncotic pressure** (present in both compartments as well) is what determines the movement of water across the endothelial cell and capillary wall between the two compartments. (Oncotic pressure **pulls in**, while Hydrostatic pressure **pushes out** and is higher in arteries than veins)
  - Starling forces will dictate fluid movement to the interstitial compartment to "bathe" the cells with nutrients and oxygen.





Barriers in ICF/ECF

- The Barrier between the ICF and ECF is the cell plasma membrane. The movement of water across it is determined by the Osmotic pressure. Osmosis is defined as a material that attracts water. If there is hyperosmolar gradient inside the cell, water will move in; and vice versa.

Osmolarity vs Osmolality?

If there is a big difference between the osmolarity and osmolality in the blood; i.e more than 10 then think of external causes such as Alcohol

L

- **OsmolaLity** = the number of osmoles per kiLo of water (mOsm/kg water).
- **Normal osmolality of body fluids: 283-292** (mOsm/kg water) usually **measured**. In the lab

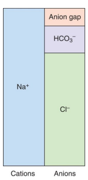
R

- **OsmolaRity** = the number of osmoles per liteR of solution (eg. plasma) (mOsm/L plasma) usually **calculated**.
- The plasma osmolarity (mOsm/L) can be calculated from the plasma concentrations of sodium, urea and glucose, as follows:

Calculated plasma osmolarity = (2 x serum [Na^+]) + blood urea + glucose

The factor of 2 applied to sodium concentration allows for associated anions. (mainly chloride and bicarbonate).

Say we have 140 cations (Na^+); we will have almost an equal amount of anions and that's why we just multiply the Na^+ by 2



Notice: here the Na is between brackets [Na^+] which means sodium CONCENTRATION, Remember concentration means that it depends on two things: (water and sodium)

plasma osmolarity mainly depends on the concentration of sodium.

For Na^+, K^+ and Cl^-:

1 mEq/L = 1 mmol/L = 1 mOsm/L

In (mEq/L) or (mmol/L) usual ~ 140

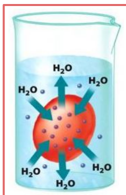
Blood urea Does Not contribute to effective osmolarity because it moves easily across cellular membrane therefore it's ignored in the calculation even with AKI.

BUT The only situation we include blood urea in calculation is when we do acute dialysis for a uremic patient, because urea crosses BBB much slower than the removal rate by dialysis "they have very high blood urea" so it might cause brain edema (Time dependent).

In (mg/dL) usual ~ 20

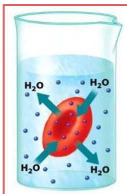
In (mg/dL) usual ~ 150

In normal situation (Glucose = 5.5 mmol) almost negligible. Unless if there's hyperglycemia.



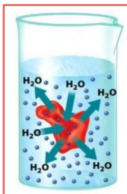
Net water gain
Cell swells

- **Hypotonic**
  - (ex. 100 mosm/L): Solutions have more water than solutes comparing to ECF



No net loss or gain

- **Isotonic**
  - (ex. 290 mosm/L): Solutions have the same solute concentration as the ECF



Net water loss
Cell shrinks

- **Hypertonic**
  - (ex. 400 mosm/L): Solutions have more solutes than water comparing to ECF

Tonicity Osmolarity?

- Osmolarity describes the solution saturation. While tonicity compares the solution to other solution (Osmolarity of solution in comparison to the plasma). So a hypertonic solution (eg. 3% Na saline I.V fluid) has a higher osmolarity than the reference point (eg. plasma).
- In medicine, it is used to compare the osmolarity of intravenous solutions to that of the serum.
- Effect of osmotic pressure on the cells:
  - To equilibrate osmotic pressures: water tends to move from solution of low osmolarity to solution of high osmolarity concentration.
- Water movement between intracellular and extracellular space (Cell membrane) is BASED on osmolarity (water move from low osmolarity to high osmolarity)
- What dictate water movement between intravascular and interstitial space (Endothelial cells)? Osmolality in addition to oncotic pressure + hydrostatic pressure (Starling forces).
- Most of the time urine is 500 mOsm/kg, it can be diluted (100 mOsm/kg) or concentrated (>800 mOsm/kg) depends on the water balance (intake, output).
- When a patient is in a catabolic state the body will produce (about 400 mOsm/Day). So, for example if the urine osmolality at maximum is 1000 mOsm/L, they will need 1000 ml of fluids to return the osmolarity to the normal state.
- To sum up, we need 1:1 ratio to maintain balance between fluids and osmolarity.

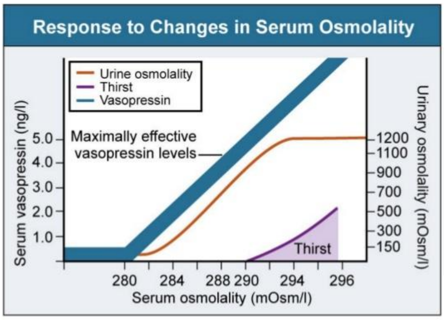
Regulation Mechanisms of Fluid and Electrolytes:

Normal filtration/Day (GFR) ≈ 125 ml/Min = 180 to 200 L/Day, and only 2 Liters of them is excreted as a urine. 99.9% has to be reabsorbed.

Regulation of osmolality and volume is achieved through thirst and the osmoreceptor-antidiuretic hormone system (vasopressin):

- Plasma hypertonicity:
  - Stimulation of Osmoreceptors in the hypothalamus → thirst
  - Stimulate secretion of ADH → ADH increases water reabsorption.
- You can live with low osmolality but you can't live with low volume. (need volume to maintain perfusion)
- Volume is more important than osmolality in controlling ADH secretion e.g. (if there is low blood volume ADH will be secreted even if there is low osmolality). e.g: In heart failure although there is low Na, the ADH is still being secreted because there is low effective arterial blood volume (EABV) sensed by the volume receptors.
- ADH shares the regulation in BOTH Na balance & water balance.
- In Ramadan → No fluid intake → Increase in water reabsorption by ADH → decrease in volume of urine and it will be concentrated
- ADH is secreted in two conditions (high osmolarity or low volume)

The regulation of volume also occurs through neurological and renal mechanisms:			
The stretch receptors (baroreceptors)	**The Renin-Angiotensin-Aldosterone System:**	**The Natriuretic peptides:**	**Kinins & Prostaglandins**
Mechanoreceptors located in the carotid sinus and in the aortic arch. Stimulus: Any change in blood pressure.	RAAS is what mainly dictate volume in the body. Decrease in renal perfusion pressure results in activation of the RAAS system. Which enhances Aldosterone releases → increases Na reabsorption from the Distal ducts.	Produced by the heart atrium in response to an increase in blood volume that leads to an increase in sodium excretion. BNP(this is the one we measure in cardiology)	Vasodilator, Holds Na. "Have a minor role"



As soon as the plasma osmolality reaches 280 mOsm/kg the secretion of ADH increases to preserve water. With that urine starts to become concentrated meaning urine osmolality will increase up to 1200 mOsm/kg but reaches a plateau when plasma osmolality reaches 290 mOsm/kg and thirst then kicks in which is stimulated by osmoreceptors.

- Normal Plasma Osmolality: 280 – 290 mOsm/kg
- Normal urine Osmolality: 100 – 800 mOsm/kg "in practice"

How do we measure the concentration of the urine?

- By checking the urine Osmolarity. Can go as low as 50 mOsmol/L and high as 1200 mOsmol/L. This is done in labs but it's time and effort consuming so we tend to look at the urine specific gravity "SG". This is an indirect way of measuring urine osmolarity.
  - For water, SG is 1.000
  - For plasma SG is 1.010
- So if urine is less than this it means it's diluted, if more than this then it's concentrated.

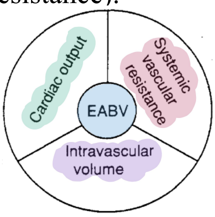
The Linear Relationship Between Urine Specific Gravity and Uosm (Plasma SG ~ 1.008)

Urine SG	Urine Osmolarity (mOsm/Kg H_2O)
1.010	300-400
1.020	700-800
1.030	1000-1200

Effective Arterial Blood Volume (EABV):

What is EABV?

➢ It is the amount of arterial blood volume required to adequately "fill" the capacity of the arterial circulation. (also determined by cardiac output and systemic vascular resistance).

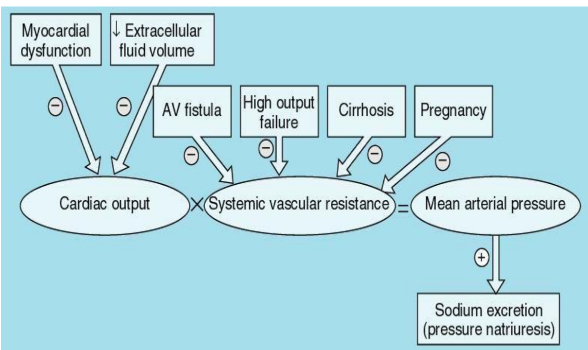


➢ *EABV has 3 components:*

a. Cardiac output
b. Systemic vascular resistance
c. Intravascular volume

➢ From the total blood volume 85% is venous, and 15% is arterial.

➢ If the arterial volume is for example 5% we have a lowered EABV.



MAP = CO x SVR
(MAP) Mean arterial pressure
(CO) Cardiac output
(SVR) Systemic Vascular resistance

CO → Depends on Stroke volume (SV) and Heart rate (HR)
SV → Depends on Ejection fraction (EF) and Preload

We treat hypertension as well as hypotension by manipulating (EF, preload, HR, and SVR).
To perfuse the organs we need good blood pressure and to have good blood pressure we need blood volume i.e preload.

↓ EABV leads to:	↑ EABV leads to :
· ↑CO · ↑Systemic vascular resistance · ↑renal Na retention = ↑ volume	· ↓ CO · ↓ Systemic vascular resistance · ↓ renal Na retention = ↓ volume

➢ **ECF volume and EABV can be independent of each other:**

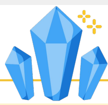
- Edematous states: increase in total ECF volume and decreased EABV
  - (eg: Heart failure, cirrhosis, nephrotic syndrome)
- Postural hypotension: may cause shifts that influence the EABV without affecting the total blood volume.

I.V FLUIDS:

Type of I.V fluid at the time of infusion	**What happens after administration of IV?**	**Examples**
Hypotonic	Water will move from ECF into ICF	• Distilled Water • 0.45% NaCl(1/2NS) • 0.33% NaCl(1/3NS)
Isotonic	It will remain in the ECF	• NS (0.9% NaCl) • Ringers Lactate 2/3 • DW-1/3 NS • 5% Dextrose in Water (D5W)
Hypertonic	Water will move from ICF to ECF	• 3% NaCl • 10%-50% Dextrose • D5W-1/2 NS • D5NS (5%Dextrose in NS) • Amino acid solution

- Before giving any type of I.V fluids you have to think of the type of solution, amount, rate and duration. You have to reassess the patient to see if you should continue with what you gave or not. etc.
- When your aim to resuscitate the patient, then you look at the blood pressure. On the other hand it you want maintain the fluid level then you have to assess the input and output
- An NPO 40 year old female having a normal blood pressure waiting for a lab call should be given D5 ½ NS + 20 KCl + 1 cc/kg/hr. K is added to hypotonic fluids

Intravenous Solutions (Crystalloids vs Colloids):



Crystalloids

Intravenous solutions that contain solutes that **readily cross** the capillary membrane

(contents: water + small electrolytes).

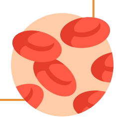
Examples: Dextrose & electrolyte solutions

Colloids

Intravenous solutions that DO NOT readily cross the capillary membrane.

(contents: water + protein). large molecules, have an osmotic effect

Examples: Blood, albumin, plasma.



- ICU physicians tend to use colloids such albumin. Patients come to ICU with blood loss so it makes sense to give them colloids; however, it takes 2 hours to prepare.
- If you need volume expander* you must use colloid or isotonic saline because you don't want fluid going inside the cell at this point, you need to maintain the perfusion of tissue which comes from raising BP.
- You may get a case in the exam with severe hypotension asking to choose the appropriate IV? albumin or NS.
- Can you give free water IV? NO because free water is a hypotonic fluid thus it will go inside the cells causing them to burst => cell lysis & thrombophlebitis (if given in peripheral line).
- All cells use ketones except RBCs, which lack mitochondria.
- General rule: 1 L water = 1Kg …. 1 L plasma ≠ 1 Kg

The Differences between each Intravenous Solutions:

This table is very important, for exam purposes you need to know which fluid is given in a particular scenario.

Solution	Components	OsmolaRity (mosm/L)	indication	Distribution (normal person) (no need to memorize)
D5W	Glucose = 5 (g/100 mL) Or 50 (g/L) It composed of 5% dextrose & water	**253** Isotonic initially, but after a while the glucose will be metabolized and driven intracellularly by insulin and the solution becomes hypotonic. **Around 285	-As maintenance fluid, the amount of glucose here is sufficient to **prevent ketogenesis** and Hypoglycemia but not nutritional. -Can be used for pt who has hypernatremia and need free water intake through IV. -NOT used for resuscitation.	If you take 1 Liter of D5W (80 ml will stay IV, 250 ml will shift to ISF & 670 ml will go inside the cell). NOT volume expander fluid bc small amount stay IV (= plasma)
Normal saline (NS) (0.9% NS)	Na=154 (mEq /L) Cl =154 (mEq /L)	308 154 Na+154 Cl =308 osmolarity Isotonic	Mainly **resuscitation** fluid (e.g. : if someone is hypovolemic you need to support blood pressure volume u should give saline) -Also given after surgery. -Can be given in a bolus.	If you take 1 Liter of NS (250 ml will stay IV and 750 ml will shift to ISF) NS is isotonic so why it will shift to another compartment? - Bc the hydrostatic pressure goes up & oncotic. When saline go to interstitial, what will happen to the patient? - Pitting EDEMA. If you keep pushing NS what will happen to Cl in plasma? - Cl will go up while bicarbonate will pushed out → dilutional acidosis.
Half saline (½ NS) (0.45% NS)	Na=77 Cl =77 A liter of half saline = half Liter of saline & half Liter of water	154 Hypotonic 77 Na + 77 Cl = 154 osmolarity	Maintenance fluid (when someone is eating a little bit, not worry about hypoglycemia, 1\2 NS is enough) -Intracellular dehydration. -Hypovolemic hyponatremic pt (Cholera). -NOT used for resuscitation.	If you take 1 Liter of ½ NS (165 ml will stay IV, 500 ml will shift n ISF & 335 ml will Go inside the cell) so ½ NS can be used when someone has intracellular dehydration, but can NOT be used when someone hypotensive ,,not resuscitation Bc only 165 stay intravenously which not support blood pressure. That's why ½ NS used as a maintenance not for replacing ACUTE volume loss.

The Differences between each Intravenous Solutions:

This table is very important, for exam purposes you need to know which fluid is given in a particular scenario.

D5 NS	Glucose =5 Na=154 Cl=154	561 -initially hypertonic but eventually after glucose burned = 308 - D5W alone is isotonic but adding NS to it makes it hypertonic	- Can be used as slow infusion for someone who needs some volume and fasting.	Same as NS (see above)
D5 ½ NS	Glucose = 5 Na=77 Cl =77	407 - Initially hypertonic but eventually after glucose burned = 154 - D5W alone is isotonic but adding ½ NS to it makes it hypertonic.	Before surgery (Any time pt fasting as maintenance fluid who is NOT hypovolemic) NOT given as bolus	Same as ½ NS (see above)
2/3 D5W + 1/3 NS	Glucose =33 (g/L) Na=50 Cl =50	285 Initially isotonic eventually hypotonic	Same as D5 ½ NS	
Ringer's Lactate	Na= 130 K=4 Ca=3 Cl=109 all in (mEq /L) Lactate = 28 (g /L) Calcium is added to Ringer's lactate as Ca is very essential for the coagulation cascade.	274 Isotonic	Used for maintenance. (Can be resuscitation fluid) -Rapid infusion will lead to increase lactic acid. -Surgeons love to use it. -Almost identical to plasma.	NOTE: More physiological "balanced" but **BE CAUTION with (AKI & sepsis)** -Bc it has k (4 mmol\L) if someone get 4 L of ringer lactate he will develop hyperkalemia. -If someone has septic shock "his liver is shocked" & has acidemia if I give lactate it will accumulate in liver and make acidemia worse. Because the liver is responsible for converting Lactate to BiCarbonate

Total body sodium content (Volume status) & serum sodium concentration (Water disorder)

Sodium and Water:

- **ECF volume** = absolute amounts of Sodium and water.
- **Plasma sodium concentration** = ratio between the amounts of Sodium and water (Concentration).
- The best test to assess volume state is urine lab test [Na^+]= sodium concentration

Basal Requirements:

Basal Water	**Calculation of Maintenance Fluids:** **4/2/1 rule:** (**4** mL/kg for first 10 kg) + (**2** mL/kg for next 10 kg) + (**1** mL/kg for every 1 kg over 20) For example, for a 70kg man: (4 × 10 = 40) + (2 × 10 = 20) + (1 × 50 = 50) Total = **110 mL/hour.**
Insensible water loss	- Stool, breath, sweat: 800 ml/d - Increases by 100-150 ml/d for each degree above 37 C.
Electrolytes	- Na:1 meq/kg/day=1 mmol/kg/day =1 mOsm /kg/day - Cl: 1 meq/kg/day - K: 1 meq/kg/day Or Na : 50-150 mmol/d (NaCl) Cl: 50-150 mmol/d (NaCl) K: 20-60 mmol/d (KCl)
Carbohydrates	- Dextrose: 100-150 g/d - IV Dextrose minimizes protein catabolism and prevents starvation ketoacidosis (enough for ketogenesis suppression not for nutritional use)

Sodium balance disorder	Water balance disorder
- Here we are talking about TOTAL Na in the body. - Disturbance of Na balance may lead to hypovolemia or hypervolemia. - The main determinant of volume is sodium content.	- Here we are talking about Na CONCENTRATION. - Disturbance of water balance may lead to hyponatremia or hypernatremia. - Water disorders: (causes a disturbance in Na concentration, not amount)
Hypervolemia = Sodium Excess ("Edema") (high volume = high sodium content)	***Hyponatremia*** = Water Excess (Low sodium conc. = high water)
Hypovolemia = Sodium Deficit ("Dehydration") (low volume = Low sodium content)	***Hypernatremia*** = Water Deficit (High sodium conc. = low water)

	Hyponatremia (Water Excess)	***Hypernatremia (Water Deficit)***
Euvolemia	SIADH	Diabetes Insipidus (DI)
Hypovolemia (Dehydration) (Sodium Deficit)	Hemorrhagic Shock with good oral water intake	Diarrhea in Children and Seniors
Hypervolemia (Edema) (Sodium Excess)	Advanced Congestive Heart Failure	Hemodialysis Patient after 3% Saline infusion for cramps

Disorder in Sodium Balance:

Clinical features of Hypovolemia & Hypervolemia:

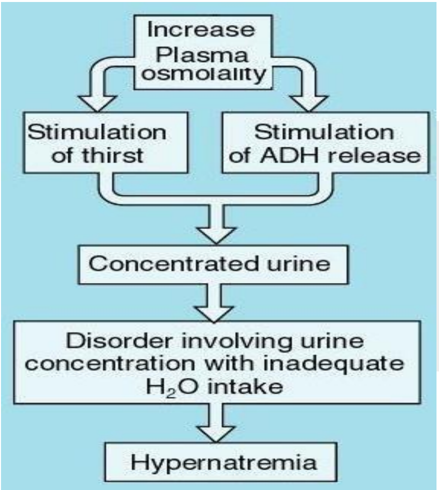
	Hypovolemia	Hypervolemia
Symptoms	Thirst Dizziness on standing Weakness	Ankle swelling Abdominal swelling Breathlessness
Signs	➢ Low JVP ➢ Postural hypotension ➢ Tachycardia ➢ Dry mouth ➢ Reduced skin turgor ➢ Reduced urine output ➢ Weight loss ➢ Confusion, stupor (unconsciousness)	➢ Raised JVP ➢ Peripheral edema ➢ Pulmonary crepitations ➢ Pleural effusion ➢ Ascites ➢ Hypertension (sometimes) ➢ Weight gain

Disorder in Water Balance:

Hypernatremia: Water Deficit Calculation

General characteristic:

- Defined as a plasma Na+ concentration >145 mmol/L
- Hypernatraemia reflects less water in relation to sodium; affected patients may or may not have a concurrent abnormality in sodium balance.
- This is less common than hyponatraemia and nearly always indicates a water deficit.



Hypernatraemia is always associated with increased plasma osmolality, which is a potent stimulus to thirst. We don't check serum osmolality in every hypernatremic patient unless we suspect something else (ex: other osmoles intake like alcohol).
Because hypernatremia is hypertonic by default = ↑Na, ↑osmolarity. Not like hyponatremia which we have to check serum osmolality because we have: Isotonic, Hypertonic and hypotonic hyponatremia.

Causes of hypernatremia:

Hypernatraemia may occur in the presence of normal, reduced or expanded extracellular volume, and does not necessarily imply that total body sodium is increased.

Hypovolemia

- Total body water ↓↓
- Total body sodium ↓

(Na deficit with a relatively greater water deficit)

This is the most common form of dehydration in pediatric and geriatric.

Urinary Na > 20

Due to renal losses:

- Loop or osmotic Diuretic (It inhibits Na reabsorption & causes water loss)
- Postobstructive diuresis (Copious amounts of salt and water are eliminated after the relief of a urinary tract obstruction)
- Intrinsic renal disease (Renal tubular function is lost → ↓↓ reabsorption of water & Na)

Urinary Na < 20

Due to Extrarenal losses:

- Burns
- Diarrhea
- Fistulas

Treatment

✔ **Correction of volume & water deficit:**

1. Pt is hypovolemic!! Administer isotonic saline till *hypovolemia* improves.
2. After that correct the *sodium level* by calculating water deficit accordingly Administer: (**Half saline** or **D5W** or **oral water** replacing the free water deficit & ongoing losses).

✔ **Treat causes of losses:**

(Removal of diuretics, insulin...)

Euvolemia (no edema)

- Total body water ↓
- No change in Total body sodium

(water deficit alone)

Some may say how come they have Euvolemia while there is a water deficit?

- These patients have subclinical hypovolemia but they are able to manage it.

Urinary Na variable

Due to renal losses:

- Diabetes insipidus

(there's high volume water loss from insufficient ADH)

- Hypodipsia

(hypodipsia refers to a partial deficiency of the thirst mechanism → person unable to feel thirsty → ↓ water intake)

Extrarenal losses:

Insensible losses:
(respiratory, dermal)

Treatment

✔ **Correction of water deficit:** calculate water deficit accordingly Administer: (**Half saline** or **D5W** or **oral water** replacing the free water deficit & ongoing losses).

✔ **In central diabetes insipidus with severe loss:** give aqueous vasopressin (ADH)"pitressin" but monitor serum Na carefully to avoid water intoxication.

✔ **Long term therapy: in nephrogenic diabetes insipidus**: (the causes of nephrogenic diabetes insipidus r: lithium, chronic kidney disease, hypokalemia, hypercalcemia. they make ADH ineffective at kidney tubule) so u have to treat NDI according to the cause: (correct plasma Ca & K conc., give amiloride for lithium induced NDI, remove offending drug)

✔ **Long term therapy:** low Na diet

Hypervolemia

- Total body water ↑

(Na retention with relatively less water retention)

Urinary Na > 20

Sodium Gains:

- Primary hyperaldosteronism (because aldosterone causes Na water retention)
- Cushing's syndrome (because high Cortisol cause mineralocorticoid effect)
- **Hypertonic dialysis**
- Iatrogenic: (hypertonic Na HCO3, NaCl tablets)

Treatment

✔ Remove Na.
✔ Discontinue offending agents.
✔ Administer furosemide.
✔ Provide hemodialysis as needed for renal failure.

These patients are given 3% saline

Principles of Treatment:

- Low Volume give Saline.
- High Volume (high Na) give Loop diuretics. Or dialysis which much less common.
- Water deficit Give free water (Oral or IV, D5W or half saline)
- Water Excess give Water restriction + Diuretics.

Water Deficit Calculation:

Water deficit: (it is the amount of "water" required to lower the Plasma Na to 140 mmol/L)

Water Deficit = Target TBW – Current TBW

- Current Total Body Water = 0.6 x Current Body Weight
- Current TBW x Current [Na+] = Target TBW x Target [Na+]
- Target TBW = $\frac{\text{current TBW} \times \text{Current [Na]}}{\text{Target[Na]}}$

- كيف نحدّد التارقت صوديوم؟ حسب السؤال، كيف؟ إذا قال لنا (حتى يرجع للطبيعي) فخلاص 140.
لكن إذا حدّد مدة مثلًا قال خلال 24 ساعة؟ هنا عندنا رينج معيّن عشان نرجّع الصوديوم للطبيعي اللي هو من **6-8** إذا أكثر من كذا يصير خطر على المريض. فلو كان معدل الصوديوم عند المريض 159 وقال السؤال خلال يوم واحد هنا كم يصير التارقت؟ بالضبط! 151

Example: 60 kg man, sodium 165 mmol/L, What's water deficit to come back to normal:

Water Deficit= Target TBW – Current TBW

Target TBW= (36 x 165)÷140=42

Current TBW= 0.6 x60=36

Water Deficit = 42 – 36 = 6 Liter (need to give 6L water plus ongoing free water loses)

- Don't forget potential for ongoing loss either from diarrhea, diuresis or insensible loss.

Clinical features:

Patients with hypernatremia generally have reduced cerebral function and cerebral dehydration. This triggers thirst and drinking, and if adequate water is obtained, is self-limiting. If adequate water is not obtained, dizziness, confusion, weakness and ultimately coma and death can result.

Hyponatremia:

General characteristic:

- This refers to too much water in relation to sodium in the serum.
- It is typically defined as a plasma Na+ concentration <135 mmol/L.

Classification of Symptoms of Hyponatremia: IMPORTANT

- All symptoms that can be signs of cerebral edema should be considered as severe or moderate symptoms that can be caused by hyponatremia:

Moderately Severe	Severe
•Nausea without vomiting •Confusion •Headache • Symptoms of hyponatremia are dependent on how fast it occurs. • Sodium means CNS symptoms, whether sodium level above the normal or below it.	•Vomiting •Cardiorespiratory distress •Abnormal and deep somnolence •Seizures •Coma (Glasgow Coma Scale [2] ≤8) For **severe** hyponatremia, Need 3% hypertonic saline as emergency treatment

The causes of Hypotonic hyponatremia (True hyponatremia) Classified Based on The Volume State:

Hypovolemia

• Total body water ↓
• Total body sodium ↓↓
(Na deficit with a relatively smaller water deficit)

Urinary Na > 20

Due to renal losses:

- Diuretic EXCESS (over time with excess use of diuretic, it will deplete the body of sodium & water)
- Mineralocorticoid deficiency (because aldosterone causes Na retention)
- Osmotic diuresis (lead to obligating electrolyte excretion):
  - Glycosuria (causes water & electrolyte losses & thereby ECF volume depletion)
  - Bicarbonaturia (↑ bicarbonate excretion also obligate renal water & electrolyte loss)
  - Ketonuria (↑ keto-acid excretion also obligate electrolyte loss)

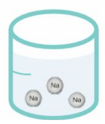
Urinary Na < 20

Extrarenal losses:

- Diarrhea
- Vomiting
- Third spacing of fluids (occurs when too much fluid moves from the intravascular space into the interstitial or "third" space):
  - Burns, pancreatitis & Trauma
- All of these are also causes of hypernatremia; however, they cause hyponatremia if there is chronic replacement with free water. A little sodium and a lot of water are lost in urine, which is then replaced with free water that has no sodium. Over time, this process depletes the body of sodium and the serum sodium level drops.
- This is what occurs in cholera patients. They do not vomit but they have severe diarrhea, later they will replace the water loss but they do not replace the Na. These patients may seize and die. This is also seen track racers. They run long distances so they sweat and lose sodium, after the race they will drink water but do not replace the sodium.

Euvolemia (no edema)

• Total body water↑
• No change in Total body sodium
(water retention alone, dilutional)

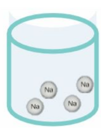


Urinary Na > 20

- In the post-operative patient there is usually a short period of **oliguria** occurring as a physiological response to surgery.
- Drug.
- Syndrome of inappropriate ADH (↑ADH increases water reabsorption)
- Hypothyroidism (hypothyroidism induces hyponatremia by inappropriate release of ADH)
- Polydipsia.
- Beer potomania (is a specific hypo-osmolality syndrome related to massive consumption of beer)

Hypervolemia

• Total body water ↑↑
• Total body sodium ↑
(Na retention with relatively greater water retention)



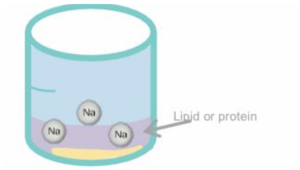
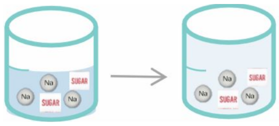
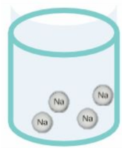
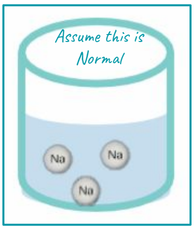
Urinary Na > 20

✔ Acute or
✔ chronic renal failure.

Urinary Na < 20

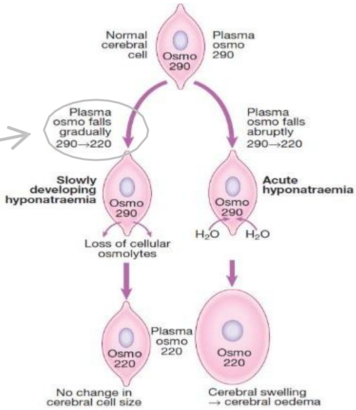
- Nephrotic syndrome (Sodium retention is primarily due to increased sodium reabsorption in the renal collecting tubules directly induced by the renal disease)
- Cirrhosis (This is through a complex mechanism, but there is vasodilatation and hence underperfusion of the volume receptors → ↑ADH)
- Cardiac Failure. (reduction in cardiac output and impaired perfusion of the volume receptors → ↑ADH)

Causes and classification (based on serum osmolality):

Isotonic (Normotonic) hyponatremia (pseudohyponatremia) (Factitious)	Hypertonic hyponatremia (Translocational Hyponatremia) (dilutional hyponatremia) (true not pseudo)	**Hypotonic hyponatremia (True hyponatremia)** The causes depend on the associated changes in extracellular volume:		
		Hyponatraemia with hypovolaemia	**Hyponatremia with Euvolemia** (water retention alone)	**Hyponatraemia with hypervolaemia**
				
Increase in plasma solids lowers the plasma sodium **concentration**. But the **amount** of sodium in plasma is normal (hence, **pseudo**hyponatremia). - Can be caused by any condition that leads to elevated protein or lipid levels. - In cases such as: sever hyperlipidemia, Myeloma, Intravenous immunoglobulin (IVIG) infusion	Results from **none Na osmoles** in serum **(often glucose or mannitol)** drawing free H2O from cells. [Na+ conc.] declines by ~2.4 mEq/L for each 100 mg/dL [5.5 mmol/L] increase in serum glucose. e.g: DM		**Discussed above**	

The effect of hyponatremia on the brain:

Osmosis = Water moves from area of low conc. of solutes to area of high conc. of solutes



Water Excess:

Example: Current TBW 30, sodium 510 mmol/L, How much water excess he has?

Water Deficit= Current TBW - Target TBW

Target TBW= (30 x 110)÷140=23.6

Water Excess = 30 – 23.6 = 6.4 Liter

Serum osmolarity gives an idea about the intracellular osmolarity because we are in osmotic balance, i.e equilibrium. Anything that occurs extracellular will cause fluids to shift either in or out. So when you measure the osmolarity in the blood this will help you to know what's happening in the cell.

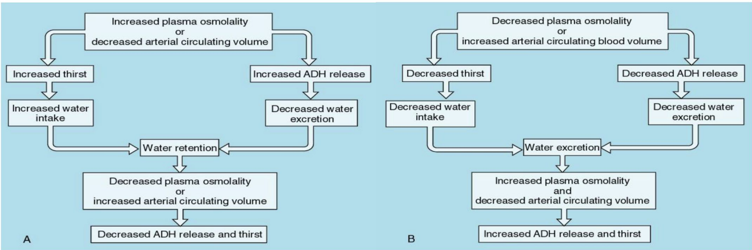
What controls sodium in our body?

- RAAS
  Sodium retention but not water. Through which mechanisms? Aldosterone works on the final step of Sodium balance. Normal GFR is 125 ml/min = 180 L/ day. Not all of it will be excreted. 99.9999% of it will be reabsorbed back. Aldosterone works in the distal tubules to reabsorb Na. How does RAAs gets secreted? Renin comes from Extraglomerular apparatus which senses how much sodium is delivered to the kidneys. In addition, we have the sympathetic tone. Remember there are multiple volume receptors which sense the amount of volume in our body. If there's hypovolemia then more Na will be absorbed but if we have hypervolemia then less Na will absorbed.

- ANP, CNP, and responsible for dumping sodium out. If i have too much then ANP will be secreted
- Do not forget the Na intake. What happens in Ramadan when we're fasting? Urine will be in small amounts and concentrated. Why? Because everything is reabsorbed except waste products, toxins, and small amounts of sodium.
  But what happens after صلاة التراويح؟ Polyurea, urine is like water(diluted, colorless and too much)

To hold volume we need water with the sodium.
The systems involved in Water maintenance are:

1. AntiDiuretic Hormone:
   - It reabsorbs water (aqueritic). It works in the collecting ducts; last part of the nephron.
   - ADH has two ways of secretion.
     i. Osmoreceptors in the throat and supraoptic nuclei, sense if the CSF (a form of interstitial fluid), same as the Plasma so any change in the osmolarity will be sensed. They have to keep the osmolarity around 290 +_ more than 300 it will be secreted and you will feel thirsty.
     ii. Volume receptors (baroreceptors), the same ones that control RAAS, Low volume? ADH will be secreted.
     In a nutshell,)
2. Thirst or intake depends on the amounts of volume in your blood. Large amount of volume? Decrease intake and vice versa. Whenever we feel thirsty this means that urine is maximally concentrated and no more water can be absorbed thus we feel thirsty.



The blood in the arterial tree is what is sensed by the baroreceptors. If the arterial blood volume drops the body will turn on the RAAs and ADH systems; on the other hand will turn off the Natriuretic Peptide system . This is what happens in diseases such as heart failure. There is an increase in the hydrostatic pressure which explains the pleural effusion, edema, and ascites. They have large amount of volume but the effectively arterial blood volume is low "Arterial Hypovolemia". The problem with this is that it's hard to measure in the BST. An indirect way to measure it is by measuring "Spot urine sodium" concentration. If RAAS is activated urine sodium will be low. This test is preferred over ANP in some hospitals because it's cheaper. It's very helpful in undiagnosed patients whom are suspected to have heart failure.

A patient comes to you with low serum sodium less than 120 mmol/ L. inside his body the cells will burst. The most dangerous one is the brain because it is a fixed space.

- The cut off point differentiating acute from chronic hyponatremia is 48 hours. Before 48 hours acute brain edema can develop but after the 48 hours the brain will start kicking out some of the osmoles out of the cells causing relief of the edema. In reality, it will be difficult to know the osmolarity of the blood of each patient within the first 48 hours, so we treat them as chronic. However symptoms can tell you, Brain symptoms are alarming and can give you a clue about the severity. Any patient with Nausea has to be treated immediately. Sodium less than 115 mmol is considered be to life threatening. So what should we give these patients? Sodium to prevent seizures, then you can adjust the volume amount.
- Studies have shown that if you increase sodium by 2-3 mmol/ L that will be enough to reduce the risk of seizure.

An approach to a patient that comes to the ER with sodium less than 120 mmol/L:
1- We take history: GI loss? Fever? Heart failure? Kidney disease? Alcohol intoxication?
2- Do a physical exam.
3- Do some lab tests: Urine sodium and urine osmolarity as this will tell you about the activity of RAAS as well as ADH.
4- At bed side I will assess volume status of the patient, clinically. What is their blood pressure? Pulse rate? Skin turgor? Distended JVP? Feeling thirsty? This will help me to know the nature of hyponatremia whether it's hypovolemic, Euvolemic, or hypervolemic? Measure the urine sodium status

Summary

IV Fluids:

4. **Hypotonic:** Water will move from ECF into ICF. E.g. Distilled Water , 0.45% NaCl (1/2NS) , 0.33% NaCl (1/3NS)
5. **Isotonic:** It will remain in the ECF. E.g. NS (0.9% NaCl) , Ringers Lactate , 2/3 DW-1/3 NS , 5% Dextrose in Water (D5W)
6. **Hypertonic:** Water will move from ICF to ECF. E.g. 3% NaCl , 10%-50% Dextrose , D5W-1/2 NS , D5NS , Amino acid solution
7. **Crystalloids** are intravenous solutions that contain solutes that readily cross the capillary membrane (contents: water + electrolytes). Examples: Dextrose and electrolyte solutions
8. **Colloids** are intravenous solutions that DO NOT readily cross the capillary membrane

Disorders in sodium balance: disturbances in balance affect the volume because sodium is the main

Differentiate between total body sodium content (volume status) and serum sodium concentration (Hypo- and Hypernatremia)

	Volume determinant of volume	
	Hypervolemia	**Hypovolemia**
Signs	Swelling in ankles and abdomen, breathlessness	Thirst, weakness, dizziness on standing.
Symptoms	High JVP, Hypertension Weight gain Peripheral edema and pleural effusion	Low JVP, Postural hypotension Weight loss Reduced urine output and dry mouth

[3] symptoms of hyponatremia are dependent on how fast it occurs

Summary

Disorders in water balance: disturbances in water are related to Na concentration, not Na amount.		
1- Hypernatremia: plasma Na+ concentration >145 mmol/L.		
Hypovolemia	**Euvolemia**	**Hypervolemia**
Total body water is decreased more than total body sodium.	Only total body water is decreased.	Total body sodium is increased more than total body water.

Disorders in water balance CONT: disturbances in water are related to Na concentration, not Na amount.		
2- *Hyponatremia*: plasma Na+ concentration <135 mmol/L		
Moderately Severe: Nausea without vomiting, Confusion, Headache		Severe Vomiting, Cardiorespiratory distress, Seizures Abnormal and deep somnolence, Coma (Glasgow Coma Scale[4] ≤8)
A. Hypotonic hyponatremia		
A.1 Hyponatraemia with hypovolaemia	**A.2 Hyponatraemia with Euvolaemia**	**A.3 Hyponatraemia with hypervolaemia**
Na deficit with a relatively smaller water deficit	Increased Total body water only.	Na retention with relatively greater water retention
B. Hypertonic hyponatremia		**C. Isotonic hyponatremia**
(Translocational Hyponatremia) (dilutional hyponatremia) (true not pseudo)		(pseudohyponatremia) (Factitious)

[4] **Glasgow Coma Scale** is neurological used to describe the general level of consciousness

Questions

1- A 47 y/o male presented to the ER with 2 days history of diarrhea. His vitals BP=75/45, HR=113 , RR=23. How would you manage this patient?

A- Normal saline

B- Half normal saline

C- Quarter normal saline

D- 5% Dextrose

2- Which of the following is regulated by ADH ?

A- Sodium

B- Potassium

C- Water

D- Sodium & water

3- **A 33 y/o male marathon runner presented to the ER with dizziness when standing and weakness. On examination, his JVP was low with reduced skin turgor . His HR = 132. Which of the following is the best initial treatment?**

A- Administration of Hypertonic saline

B- Administration of Isotonic saline

C- Administration of Hypotonic saline

D- No intervention, only observe the patient.

4- A **27 y/o female patient presented to you with pain in her right forearm associated with redness, warmth of the skin and tissues after she had an IV fluid because of her hypovolemia. What is the most likely cause of her symptoms ?**

A- Administration of Ringer's lactate

B- Administration of ½ Na

C- Administration of pure water

D- Administration of Na

5- The nurse evaluates which of the following patients to be at risk for developing Hypernatremia ?

A- 50 y/o with pneumonia, diaphoresis and high fever

B- 62 y/o with CHF taking loop diuretics

C- 39 y/o with vomiting and diarrhea

D- 60 y/o with lung cancer and SIADH

Questions

6- 83 y/o patient admitted with heart failure and a Sodium level of 113 mEq/L. He is behaving aggressively toward staff and does not recognize family members. When the family expresses concern about his behavior, the doctor would respond most appropriately by stating :

A- The patient may be suffering from dementia, and the hospitalization has worsened the confusion.

B- Most older adults get confused in the hospital.

C- The Sodium level is low, and the confusion will resolve as the levels normalize.

D- The sodium level is high and the behavior is a result of dehydration.

7-Which of the following is best to be given for a patient with hypoglycemia ?

A- ½ NS

B- NS

C- D5 ½ NS

D- D10W

8-A decrease in effective arterial blood pressure will lead to:

A- Increased renal absorption of Na

B- Decreased renal absorption of Na

C- Increased renal excretion of Na

D- Decreased stroke volume

9- Woman with hypertension on Hydrothiazide came to ER, her Na level is 114. She was given 3% normal saline. Her Na level in the next 24 hours should not exceed?

A- 118

B- 126

C- 130

D- 138

Answers:

1.A

2.D

3.B

4.C

5.A

6.C

7.D

8.A

9.B